Palaeoglaciation of Parque Natural Lago de Sanabria, northwest Spain

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A B S T R A C T

Detailed geomorphological mapping provides evidence for at least three phases of glaciation in the Parque Natural Lago de Sanabria, in northwest Spain. The most extensive glaciation was characterised by a large plateau ice cap. A combination of geomorphological evidence and glacier modelling indicates that this ice cap covered an area of more than 440 km², with a maximum ice thickness of c. 300 m and outlet glaciers reaching as low as 1000 m. This represents the largest ice mass in Iberia outside the Pyrenees and one of the largest in the mountains of southern Europe and the Mediterranean region. Radiocarbon dates from the base of lacustrine sequences appear to suggest that the most extensive phase of ice-cap glaciation occurred during the last cold stage (Weichselian) with deglaciation occurring before 14–15 ka 14C BP. A second phase of glaciation is recorded by the moraines of valley glaciers, which may have drained small plateau ice caps; whilst a final phase of glaciation is recorded by moraines in the highest cirques.

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1. Introduction

The small size and marginal location of Mediterranean glaciers make them very responsive to changes in climate (Messerli, 1967, 1980; Hughes et al., 2006a,b). The former glaciers of Iberia are particularly important for understanding Pleistocene cold-stage climates. This is because of their proximity to the North Atlantic and the fact that the Polar Front, important in the development of depression weather systems, migrated south as far as western Iberia (Ruddiman and McIntyre, 1981) during cold periods. This has important implications for moisture supply to the Mediterranean region during Pleistocene cold-climate events, which have long been the subject of intense debate and speculation (e.g., Butzer, 1957; Tzedakis, 2007). The glacial record can potentially provide important clues for understanding the state of the atmosphere, because glaciers are closely related to air temperature and precipitation (Ohmura et al., 1992; Hughes and Braithwaite, 2008).

The largest Pleistocene glaciers in Iberia formed in the mountain ranges of the north and west (see review by Perez Alberti et al., 2004). The most extensive glaciers were found in the Pyrenees as a result of the northerly location and high altitude of this mountain range (Calvet, 2004). However, substantial glaciers also formed in the Cantabrian Mountains in northern Spain and the Serra da Estrela in Portugal, as well as in some of the mountains of the Iberian interior and the Sierra Nevada in the far south (Perez Alberti et al., 2004; Vieira, 2007). In northwestern Spain, Vega Ureta and Aldasoro Martin (1994) identified a range of glacial features in the Parque Natural Lago de Sanabria (Fig. 1). In this area, outlet valley glaciers drained radially from a large ice cap centred on the Sierra Segundera, the largest of which occurred in the Valle del Tera (Fig 1).

The main focus of this paper is to improve the understanding of the glacial geomorphological record and the geometry-hypsometry of associated former ice masses in the Parque Natural Lago de Sanabria. The paper aims to i) provide a detailed understanding of the glacial geomorphology, with a focus on the Valle del Tera; ii) establish how many glacial phases are recorded in the geomorphological record; and iii) provide an accurate and realistic reconstruction of the geometry and hypsometry of the former ice mass during the most extensive phase of glaciation.

2. Study area

This study was undertaken in the Parque Natural Lago de Sanabria of NW Spain (Fig. 1), which comprises two undulating mountain plateaux, the Sierra Segundera in the west and the Sierra de la Cabrera Baja in the east. The highest mountain in the park is Peña Trevinca, 2126 m asl, located at the northern end of the Sierra Segundera (42°15’ N 6°47’ W). A deep valley, the Valle del Tera, runs south and then east from the foot of this peak, dividing the two plateaux. This valley forms the focus of the study.

The mountains that comprise the Parque Natural Lago de Sanabria national park were formed from Cambrian and Silurian rocks during the Alpine orogeny (Vega Ureta and Aldasoro Martin, 1994). In the southern parts, granitic gneisses produce a craggy but rounded topography, whilst the steep-sided plateaux margins (at the northern extreme of the park) are generated by bands of slate and quartzite. Climatically, the park lies on the boundary between the relatively maritime north coast of Iberia and the arid plains to the south. Average
annual rainfall across the park is in the region of 1000–1600 mm, and the mean annual temperature in the lower Valle del Tera valley is c. 12 °C (Allen et al., 1996).

3. Field methods

The distribution and nature of landforms indicating glacial activity were recorded through geomorphological mapping of the Valle del Tera catchment. Mapping was undertaken using 1:25,000 and 1:50,000 scale base maps produced by the civilian Instituto Geográfico Nacional and military Servicio Geográfico del Ejército respectively. A range of geomorphological features indicative of past glaciation were mapped onto these sheets. The features identified included depositional features (frontal and lateral morainic ridges, recessional moraines, hummocky moraine, limits of till cover, perched boulders), erosional features (glacial troughs, cirques, glacially scoured and moulded bedrock, roches moutonnées), and ice ice-marginal forms (kame terraces). Where encountered, exposures were logged and analysed. Periglacial features were also noted. This field-based surveying was aided by the use of aerial and satellite photography.

Fig. 1. Location map of the Valle del Tera in the Parque Natural Lago de Sanabria. Numbered locations are referred to in the text description of the geomorphological evidence.
Fig. 2. Glacial geomorphological map of the Valle del Tera. Radiocarbon dates are from basal lake/marsh sediments (from Allen et al., 1996; Muñoz Sobrino et al., 2004).
4. Field evidence

The location of sites mentioned in the text are shown in Fig. 1. The interpreted glacial geomorphology of the Valle del Tera is given in Fig. 2.

4.1. Geomorphology

The head of the Valle del Tera takes the form of a cluster of cirques, with lip altitudes of c. 1700–1900 m. These drain into a U-shaped valley at 1600 m [1], gently descending 100 m over 7 km (Fig. 3). The surrounding topography is steep but rounded, with few crags. Notable exceptions are the craggy backwalls of the deep cirques found to the north [2] and south [3] of Peña Trevinca.

The region's two highest peaks, Peña Trevinca (2127 m) [4] and Peña Negra (2121 m) [5], are topped by craggy, frost-shattered summits above c. 2050 m, in contrast to the rounded summits of the surrounding plateaux of the Sierra Segundera and Sierra de la Cabrera. Peña Trevinca and Peña Negra are the only two peaks to possess craggy, frost-shattered summits. This may be partly a result of their location within a band of slate. However, other summits in this band do not share this morphology. As such, it suggests they may have been the only nunataks to protrude above a former ice cap in this area, with a maximum ice surface altitude of c. 2050 m.

The upper section of the Valle de Tera contains a number of significant depositional features. Cirque [2] shows four ridges of deposited material, while cirques [6] and [7] also show at least two ridges each. Cirques [8] and [9] showed only one ridge each, at the mouth of the cirque, and hummocks of deposited material were found on the valley below the cirque [10].

The lake of Embalse Vega de Conde [11] is situated upvalley of two large (c. 5 m high) sediment ridges. Here, a moraine complex marks the terminus of a large valley glacier that preceded the cirque glaciation. Downvalley of the Embalse Vega de Conde low sediment hummocks continue downstream for around 2 km. These are interpreted as hummocky moraine and most likely formed during glacier recession.

The plateau edges of the Sierra Segundera and Sierra de la Cabrera, either side of the Valle del Tera, are characterised by smoothed streamlined bedrock terrain at altitudes exceeding 1900 m in places. This terrain is particularly widespread in the southern parts of the Sierra Segundera. The smoothed streamlined bedrock terrain is interpreted as ice-moulded and suggests that the plateau surfaces were covered by ice and drained into the Valle del Tera. At the plateau edges and surfaces below c. 1950 m, ice would have been sufficiently thick to erode forming the striking ice-moulded terrain. This implies that the surface of the ice cap would have been close to 2000 m asl — which is consistent with the altitude of the trimlines on the highest summits Peña Trevinca (2127 m) and Peña Negra (2121 m) described above.

South of the Embalse de Vega de Tera [12], a change in the underlying bedrock is noted, and the Rio Tera enters a craggy gorge (the Cañon del Tera) that descends 500 m over 6 km to reach an altitude of 1000 m. Here the river is cut into the base of a U-shaped trough. Ice-moulded bedrock is abundant in this area. Subglacial meltwater channels are also evident, with Nye channels cut into bedrock and oriented counter to gravitational drainage (Fig. 4). On the western side of the valley, several arcuate diamicton ridges are found in small valleys descending the steep slopes from the plateau to the west. The abundance of glacially moulded bedrock clearly shows that the U-shaped form of the Cañon del Tera was created through erosion by warm-based ice. The diamicton ridges in the western tributaries of the Cañon del Tera are interpreted as moraines formed by glaciers draining from the Sierra Segundera plateau.

Numerous tors, consisting of angular up-standing bedrock, are present on the eastern side of the Cañon del Tera [13–15]. The existence of these tors suggests that this area remained unglaciated during the most extensive glaciation phase.
At the foot of the Cañon, the Valle del Tera joins with a similar valley draining from the west [16]. Here, it turns to the east across delta sediments and the 3 km length of Lago de Sanabria. Large sediment ridges bound the lake to the north and south with flat platform surfaces present where these ridges cross tributary valleys. Lago de Sanabria is dammed on its eastern side by a low ridge of bouldery diamicton [17], one of several sediment ridges that cross the valley in this area (Fig. 5). Boulders, some several metres in height, are scattered abundantly across the land to the east and southeast of the lake. The sediment ridges are interpreted as lateral and terminal moraines of a former valley glacier. These, together with the spread of glacially transported boulders to the east and southeast of the lake, represent the most extensive phase of glaciation recorded in this valley. The platform surfaces are interpreted as kame terraces, formed by the infilling of ice-marginal lakes created when the ice dammed the tributary valleys.

Downvalley of the outermost moraines, to the SE of Lago de Sanabria, diamicton deposits are replaced by thick accumulations of sands and silts, which are exposed in several sections (Fig. 2). These deposits are interpreted as representing glaciofluvial outwash associated with the former ice limit at Lago de Sanabria.

4.2. Morphostratigraphical summary

Overall, 3 discrete phases of glaciation can be differentiated in the geomorphological record (Fig. 6). In this context, the term “phase” is not intended to be viewed as a formal chronostratigraphical division—primarily because of the lack of dating and the uncertainties regarding the precise position of the glacial units in time. The inherently fragmentary character of the sequence of events reconstructed from moraines and glacial surfaces inhibits establishment of a formal chronostratigraphical terminology, since this ideally necessitates a continuous parastratotype preferably in close proximity (Hughes et al., 2004a,b). Nevertheless, the morphostratigraphical subdivision
described below provides a useful preliminary basis for understanding the glacial history of this area.

4.2.1. Phase I: extensive ice-cap glaciation

In the lower valley, the maximum advance of ice is marked clearly by large lateral moraines to the north and south of Lago de Sanabria and by the boulder limit to the east. This valley glacier drained extensively glaciated uplands on the Sierra Segundera and Sierra de la Cabrera plateaux. The geomorphological evidence from the upper Valle del Tera suggests that the ice surface level in this area may have been c. 2050 m, high enough to cover the plateau.

4.2.2. Phase II: upland glaciation

Moraines in the western tributaries of the Cañon del Tera provide evidence of valley glaciers that flowed down the western flanks of the Sierra Segundera. However, whether they existed as independent ice masses or drained a larger ice cap on top of the plateau remains unclear. These moraines are stratigraphical equivalents of moraine arcs located at the Embalse Vega de Conde in the upper section of the

Fig. 6. The phases of glaciation of the Valle del Tera. (A) phase I: extensive ice cap glaciation; (B) phase II: upland glaciation; (C) phase III: cirque glaciation. Solid lines indicate ice margins constrained by geomorphological evidence. Shaded areas demark areas glaciated during the corresponding phase.
Valle del Tera. The location of the drift limits on the eastern valley side suggests that at this point the ice surface rose to an altitude of c. 1750 m, originating from the cluster of cirques at the head of the valley.

4.2.3. Phase III: cirque glaciation

The final set of moraines is that found in the cirques at the head of the valley. These represent a final phase of glaciation in which only the cirques were occupied by ice.

5. Glacier reconstruction — methods

The geomorphological evidence from the Valle del Tera described above was combined with observations of glacial limits in neighbouring valleys by Vega Ureta and Aldasoro Martin (1994) to delimit the approximate boundaries of the ice cap during the most extensive glaciation phase (phase I — extensive ice-cap glaciation). In order to estimate the thickness of ice that may have accumulated on the Sierra Segundera and Sierra de la Cabrera plateaux, a parabolic equation devised to produce surface profiles for ice sheets resting on flat horizontal beds was employed (Orowan, 1949; Nye, 1952; Rea et al., 1998). This is defined as

\[ h = \left( \frac{2t_b x}{pg} \right)^{1/2} \]

where \( h \) is ice thickness at centre, \( t_b \) is basal shear stress (estimated at 50 kPa from low bed slope angles), \( x \) is distance from the margin to the ice divide, \( p \) is the density of ice (0.9167 g cm\(^{-3}\)), and \( g \) is the acceleration from gravity (9.80665 m/s\(^2\)).

Fig. 7. Reconstruction of the Sanabria ice cap. The Valle del Tera is clearly visible draining the eastern portion of the former ice cap with a distinct outlet lobe situated in the area of the current Lago de Sanabria. The limits of the westernmost portion of the ice cap are unknown. In addition, evidence of glaciation in the northeastern area has not been mapped. Glacial limits outside the Valle del Tera catchment, which is well-constrained in this study, are based on satellite imagery and on observations of former glacier termini by Vega Ureta and Aldasoro Martin (1994). Arrows denoting ice flow are based on the location of zones of ice-scoured bed rock.
This was applied to a range of points across the plateaux, taking the value of x as the distance from the edge of the plateau, providing a series of spot heights for the thickness. These were added to the altitude of the underlying topography, and the ice surface was contoured accordingly. These contours were then adjusted slightly to fit observed glacier dynamics, with ice thickness being reduced in areas where there is significant “draw down” from outlet glaciers or where the ice surface is steep (Paterson, 1994; Rea et al., 1998).

Reconstruction was not attempted north of the plateaux because the geology of this area is significantly different to the field surveyed area.

The Valle del Tera outlet glacier was used to calculate the equilibrium line altitude (ELA) of this catchment of the former ice cap. The lower and upper margins of glaciation in this valley are now very well constrained based on the geomorphological evidence described above, and this part of the ice cap reconstruction can be considered as the most reliable. The ELA was calculated using several different approaches including the median elevation of the glacier (MEG) method (see Benn and Lehmkuhl, 2000; note that this method simply reflects a toe-to-headwall ratio of 0.5 and does not represent the true median elevation of the glacier as recognised in Braithwaite and Müller (1980), where the median elevation divides the glacier surface into two parts of equal area), the area-weighted mean–altitude (AWMA) method (Sissons, 1974), and also using assumed accumulation area ratios. Modern mid-latitude glaciers tend to have AARs in the range 0.5–0.8 (Meier and Post, 1962; Hawkins, 1985), and this range of AARs was applied to the Valle del Tera glacier catchment. None of these methods are perfect when reconstructing former glacier ELAs; they are either too crude, rely on flawed assumptions regarding the mass balance curve or do not take into account glacier hypsometry, or all these (Sutherl and, 1984; Benn and Lehmkuhl, 2000).

The problems associated with the methods of ELA reconstruction described above can be avoided using an alternative method based on the area-altitude balance ratio (AABR), which takes into account the former hypsometry of the glacier surface and uses a balance ratio to describe the difference between ablation and accumulation gradients (Osmaston, 1975). In the case of the former Serra da Estrela ice cap in Portugal, Vieira (2007) assumed a balance ratio of 2 to reconstruct the ELA, which is representative of modern-day, mid-latitude maritime glaciers (Benn and Gemmell, 1997; Rea, 2009). Rather than assume a single value for the balance ratio on the Valle del Tera glacier catchment, a range of values were used, and associated ELAs were tested against the ELAs reconstructed using the other techniques described above. In this way, realistic values of the balance ratio on the former Valle del Tera glacier catchment can be determined, and it is similar to the approach adopted for Scottish palaeoglaciers by Ballantyne (2007).

### 6. Glacier reconstruction — results

A reconstruction of the Sanabria ice cap during the most extensive recorded phase of glaciation (phase I — extensive ice-cap glaciation) is presented in Fig. 7. The Sanabria ice cap covered an area of at least 440 km². The actual size of the ice cap may have been substantially larger because the ice extent in northeastern valleys has not been defined, neither have the westernmost limits of the ice cap. At least three ice centres can be identified: one over the southern Sierra Segundera, one over the northern Sierra Segundera, and another over the Sierra de Cabrera. The ice cap reached a maximum thickness of c. 300 m at the ice shed between the two ice centres over the Sierra Segundera plateau.

Equilibrium line altitude (ELA) values for the Valle del Tera catchment of the former ice cap, calculated using a range of different methods, are presented in Table 1. They are in the range 1520–1900 m. An AAR of 0.8 provides the lowest estimate of the ELA at 1520 m, and an AAR of 0.5 provides the highest estimate of the ELA at 1900 m. All other methods produce values within this range. Balance ratios of 1–3 correspond to ELAs in the range 1832–1620, corresponding to AARs of 0.6–0.77. The AWMA method produces an ELA of 1771. This method is known to overestimate the ELA (Sutherland, 1984) and, thus, values lower than this calculated using other methods are likely to be more realistic. The median of all the values calculated using the different methods is likely to be closest to the real former ELA on the former Valle de Tera glacier catchment. This produces an estimated ELA of 1687 m, which is equal to the ELA calculated using a balance ratio of 2, which coincidently is within the range of values often cited as the balance ratio most representative of mid-latitude maritime glaciers (Benn and Gemmell, 1997; Rea, 2009) as noted earlier.

### 7. Discussion

The Sanabria ice cap was the largest ice mass in Iberia, outside the Pyrenean mountains, and one of the largest ice masses recorded in southern Europe during the Pleistocene. The ice cap, with an area of at least 440 km², was several times larger than the ice cap on Portugal’s Sierra da Estrela, which covered an area of 66 km² (Vieira, 2007). However, the ELA of the Valle del Tera catchment of the Sanabria ice cap was, at 1687 m, similar to the overall average ELA on the Estrela ice cap (ELA = 1650 m) (Vieira, 2007). This represents an estimated ELA depression of c. 1000 m compared with Late Holocene ELAs (Messerli, 1980; González Trueba et al., 2008).

Both the Sanabria and Estrela ice-cap glaciations have not yet been directly dated. However, several clues point to the age of glaciation in the Sanabria area. Vega Ureta and Aldasoro Martin (1994) attributed the major moraine systems to the “Würmian” (=Weichselian) glacia- tion based on a pollen sequence taken from a marsh resting upon the moraines around Lago de Sanabria by Menendez Amor and Florschütz (1961) (Fig. 1). A Late Pleistocene age for the moraines bounding Lago de Sanabria is supported by the findings of Muñoz Sobrino et al. (2004) who presented evidence from Laguna de las Sanguijuelas, a small lake basin in a morainal depression to the northeast of Lago de Sanabria, indicating that the basal sediments date from 14.78±0.19 ¹³C ka BP (The lake basin described by Muñoz Sobrino et al. (2004) is sometimes referred to as Charca de las Sanguijuelas (Fig. 1) and, confusingly, this site is not the same as Laguna Sanguijuelas, which is marked to the south of Lago de Sanabria on the Instituto Geográfico Nacional map). Allen et al. (1996) dated organic material in the basal sediments of two glacial lake sequences — Sanabria marsh and Laguna de Roya (Fig. 2). At Sanabria marsh, an infilled lake basin located at 1085 m altitude to the southeast of Lago de Sanabria, basal deposits yielded an age of 12.58±0.06 ka ¹³C BP (Figs. 1 and 2). At Laguna de la Roya, located at 1608 m in the Sierra Segundera, basal deposits yielded a similar age of 12.94±0.1 ka ¹³C BP (Figs. 1 and 2). When extrapolated to the base of the lacustrine sequences, these ages suggest that lacustrine sedimentation was initiated in these basins at c.14–15 ka ¹³C BP (Allen et al., 1996) in accordance with the dated sequence from the Sanguijuelas marsh (Muñoz Sobrino et al., 2004). If this geochronology represents the onset of deglaciation, then the most extensive glaciers were present in this area during the classical Late Weichselian or Würmian Substage, i.e. marine isotope stage (MIS) 2. This would then imply that the smaller phase II and phase I glaciations occurred later, possibly during the late-glacial. However, the chronostratigraphical position and geochronology of the glacial units in the Parque Natural Lago de Sanabria remains very uncertain.

### Table 1

<table>
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<th>Glacier catchment</th>
<th>MEG</th>
<th>AWMA</th>
<th>AAR</th>
<th>BR</th>
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<td>1600</td>
<td>1771</td>
<td>1900</td>
<td>1520</td>
<td>1687</td>
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</table>

MEG = median elevation of glacier; AWMA = area-weighted mean-altitude method; AAR = accumulation area ratio; BR = balance ratio. The overall median of the ELA values calculated using the different techniques was 1687 m, corresponding to that calculated using a balance ratio of 2. See text for details.
Elsewhere in Iberia, geochronological frameworks exist for glacial sediments and landforms in several mountain areas. In the Redes Natural Park of the Cantabrian Mountains, the most extensive glacial advance occurred before 28.99 ± 0.23 14C ka BP (34.12 ± 0.52 cal. ka BP) (Jiménez Sanchez and Farias Arquer, 2002). The dates from the Redes Natural Park imply that the maximum advance of glaciation during the last glacial stage took place much earlier than the global last glacial maximum (LG M)—a situation also suggested for the Pyrenees, and the subject of recent debate (Hughes and Woodward, 2008).

In the Serra de Quixena and Serra da Gérez to the west of the Sanabria region, 23Ne and 36Be cosmogenic isotope analyses have been applied to date glacially polished bedrock surfaces and push-moraine boulders (Vidal-Romaní et al., 1999; Fernandez Mosquera et al., 2000; Vidal-Romaní and Fernández-Mosquera, 2006). Three glacial phases have been identified. The oldest was dated to before c. 232 ± 48 ka (MIS 8), an intermediate phase to c. 135 ± 31 ka (MIS 6), and the youngest to c. 16 ± 8 ka (MIS 2) (Vidal-Romaní and Fernández-Mosquera, 2006). The youngest age is supported by a radiochronic date of 13.4 ± 0.4 14C ka for the base of lacustrine sediments from a glacial lake in the same area (Vidal-Romaní et al., 1999). This sequence of glaciation, with the oldest glaciations corresponding to the Middle Pleistocene with a smaller, less extensive, glaciation during the Late Pleistocene is similar to that found in the eastern Mediterranean in Greece (Hughes et al., 2006c, 2007).

However, in central Spain, Palacios et al. (2007) reported a rather different story using 36Cl exposure ages for glacial landforms in the Sierra de Gredos and Sierra de Guadarrama. These dates place the most extensive glaciation in these mountains at c. 21 ka—a period of the global LG M. No earlier glacial formations were found in this area, in contrast to the record from the Serra de Quixena and Serra de Gérez massifs discussed above.

The geochronology of glaciations in Iberia remains unclear. In many of the Iberian mountains, including those of the Parque Natural Lago de Sanabria, cosmogenic nuclide analyses are likely to offer the best potential for understanding the timing of glaciation. An extensive sampling network utilising a range of nuclides (10Be, 26Al, 36Cl, 3He, 21Ne) on different lithologies is required to avoid ambiguities that plague the current understanding of the geochronology of glaciations in this region. This could also be supplemented by Uranium-series dating of moraines (cf. Hughes et al., 2006c) in glaciated carbonate areas, such as the Picos de Europa.

The presence of such a large ice cap in Iberia has important bearing on palaeocirculation during Pleistocene cold stages. The low ELA of the eastern portion of the ice cap draining into the Valle del Tera would have required high volumes of accumulation in order to offset high summer melting at this relatively low altitude. This is consistent with the movement of North Atlantic depression tracks across Iberia into the western Mediterranean region during cold periods (Florineth and Schlüchter, 2000). However, a comprehensive programme of glacial geomorphological mapping, dating and glacier-climate reconstruction is needed from other mountain areas at the Atlantic-Mediterranean interface, such as in the Atlas Mountains of North Africa (Hughes et al., 2004a,b), as well as other mountain areas of Iberia. Also, in order to properly understand the palaeoclimatic implications of the former Sanabria ice cap, further dating is necessary, as is the case in most other mountains of Iberia and North Africa. Nevertheless, this paper provides important new information on the detailed glacial geomorphology of the Sanabria region, in NW Spain, and the geometry and hypsometry of the former Sanabria ice cap during the most extensive phase of glaciation.

8. Conclusion

Three phases of glaciation are evident in the glacial geomorphological record of the Parque Natural Lago de Sanabria. The most extensive phase of glaciation was characterised by a large plateau ice cap, covering an area of more than 440 km². The eastern portion of this ice cap was drained by a large outlet glacier reaching an altitude as low as 1000 m in the Valle del Tera. A second phase of glaciation was characterised by valley glaciation, possibly fed by small ice caps on the plateaux. The third and last phase of glaciation in this area was characterised by cirque glaciers. Radiocarbon dates from the base of lacustrine sequences imply that the most extensive phase of ice-cap glaciation occurred during the last cold stage, with deglaciation occurring before 14–15 ka 14C BP (Allen et al., 1996; Muñoz Sobrino et al., 2004). However, this remains tentative, and a comprehensive dating programme is now needed to establish the geochronology of glacial phases in the Parque Natural Lago de Sanabria, building on the detailed glacial geomorphological framework now in place.

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